

Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.



A SUGAR BEET FOUR MONTHS OLD AFFECTED WITH CURLY-TOP.
(Natural size.)

U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN NO. 122.

B. T. GALLOWAY, *Chief of Bureau.*

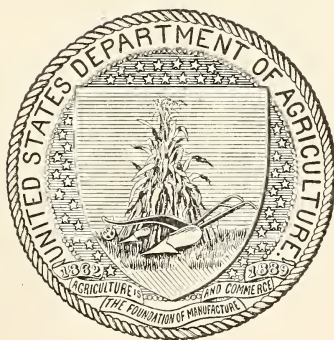
CURLY-TOP, A DISEASE OF THE SUGAR BEET.

BY

C. O. TOWNSEND,

PATHOLOGIST IN CHARGE OF SUGAR-BEET INVESTIGATIONS.

ISSUED APRIL 25, 1908.



WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1908.

BUREAU OF PLANT INDUSTRY.

Pathologist and Physiologist, and Chief of Bureau, Beverly T. Galloway.
Pathologist and Physiologist, and Assistant Chief of Bureau, Albert F. Woods.
Laboratory of Plant Pathology, Erwin F. Smith, Pathologist in Charge.
Investigations of Diseases of Fruits, Merton B. Waite, Pathologist in Charge.
Laboratory of Forest Pathology, Haven Metcalf, Pathologist in Charge.
Truck Crop Diseases and Plant Disease Survey, William A. Orton, Pathologist in Charge.
Plant Life History Investigations, Walter T. Swingle, Physiologist in Charge.
Cotton Breeding Investigations, Archibald D. Shamel and Daniel N. Shoemaker, Physiologists in Charge.
Tobacco Investigations, Archibald D. Shamel, Wightman W. Garner, and Ernest H. Mathewson, in Charge.
Corn Investigations, Charles P. Hartley, Physiologist in Charge.
Alkali and Drought Resistant Plant Breeding Investigations, Thomas H. Kearney, Physiologist in Charge.
Soil Bacteriology and Water Purification Investigations, Karl F. Kellerman, Physiologist in Charge.
Bionomic Investigations of Tropical and Subtropical Plants, Orator F. Cook, Bionomist in Charge.
Drug and Poisonous Plant Investigations and Tea Culture Investigations, Rodney H. True, Physiologist in Charge.
Physical Laboratory, Lyman J. Briggs, Physicist in Charge.
Crop Technology and Fiber Plant Investigations, Nathan A. Cobb, Crop Technologist in Charge.
Taxonomic and Range Investigations, Frederick V. Coville, Botanist in Charge.
Farm Management Investigations, William J. Spillman, Agriculturist in Charge.
Grain Investigations, Mark A. Carleton, Cerealist in Charge.
Arlington Experimental Farm, Lee C. Corbett, Horticulturist in Charge.
Vegetable Testing Gardens, William W. Tracy, sr., Superintendent.
Sugar-Beet Investigations, Charles O. Townsend, Pathologist in Charge.
Western Agricultural Extension Investigations, Carl S. Scofield, Agriculturist in Charge.
Dry-Land Agriculture Investigations, E. Channing Chilcott, Agriculturist in Charge.
Pomological Collections, Gustavus B. Brackett, Pomologist in Charge.
Field Investigations in Pomology, William A. Taylor and G. Harold Powell, Pomologists in Charge.
Experimental Gardens and Grounds, Edward M. Byrnes, Superintendent.
Foreign Seed and Plant Introduction, David Fairchild, Agricultural Explorer in charge.
Forage Crop Investigations, Charles V. Piper, Agrostologist in Charge.
Seed Laboratory, Edgar Brown, Botanist in Charge.
Grain Standardization, John D. Shanahan, Expert in Charge.
Subtropical Laboratory and Garden, Miami, Fla., Ernst A. Bessey, Pathologist in Charge.
Plant Introduction Garden, Chico, Cal., August Mayer, Expert in Charge.
South Texas Garden, Brownsville, Tex., Edward C. Green, Pomologist in Charge.
Cotton Culture Farms and Farmers' Cooperative Demonstration Work, Seaman A. Knapp, Special Agent in Charge.
Seed Distribution (Directed by Chief of Bureau), Lisle Morrison, Assistant in General Charge.

Editor, J. E. Rockwell.
Chief Clerk, James E. Jones.

LETTER OF TRANSMITTAL

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF PLANT INDUSTRY,
OFFICE OF THE CHIEF,
Washington, D. C., January 28, 1908.

SIR: I have the honor to present herewith the manuscript of a bulletin entitled "Curly-Top, a Disease of the Sugar Beet," by Dr. C. O. Townsend, Pathologist in Charge of the Sugar-Beet Investigations of this Bureau. I recommend that it be published as Bulletin No. 122 of the Bureau series.

The bulletin presents the results of the investigations and observations by this Bureau during the past six years. It deals with one of the most destructive diseases of the sugar beet, and while the results obtained thus far are in the main negative, the object in presenting them at this time is twofold: (1) To encourage the growers of sugar beets by showing them that the presence of this disease in their locality during a certain season is not an indication that it has become a permanent factor in the cultivation of sugar beets in that locality, and (2) to assist other experimenters and observers in their efforts to find the real cause of the disease by bringing together the results of what has already been done by this Bureau to that end, thus preventing useless repetitions. It is the purpose to continue the investigations along all possible lines that promise a solution of the problem until the exact cause of curly-top is known and a satisfactory remedy for its control discovered.

Respectfully,

B. T. GALLOWAY,
Chief of Bureau.

Hon. JAMES WILSON,
Secretary of Agriculture.

CONTENTS.

	Page.
Symptoms of curly-top	7
Occurrence of curly-top	8
Names of the disease	10
Possible causes of curly-top.	13
Bacteria.....	14
Fungi.....	14
Fungi attacking the leaves.....	14
Fungi attacking the roots.....	15
The use of fungicides.....	16
Insects.....	17
Abnormal moisture supply.....	18
Entire seed bed too dry.....	18
Insufficient supply of moisture at taproot.....	18
Entire seed bed too wet.....	19
Moisture supply too variable.....	19
Water too cold when applied to plant.....	20
Abnormal soil conditions.....	20
Seed bed too cold.....	20
Seed bed too warm.....	21
Subsoil too hard.....	21
Lack of available plant food in the soil.....	21
Lack of humus in the soil.....	22
Too much alkali in the soil.....	23
Soil too acid.....	24
Improper preparation of the seed bed.....	25
Improper cultivation of the beets.....	25
Insufficient supply of air around the roots.....	26
Abnormal atmospheric conditions.....	27
Atmosphere too cold at time of germination.....	27
Hot, dry winds.....	27
Poor seed	28
Combination of unfavorable conditions.....	29
Nonconsecutive appearance of curly-top.....	30
Beets resistant to curly-top.....	30
Communicability of curly-top.....	31
Persistence of curly-top.....	31
Summary.....	32
Description of plates.....	34
Index.....	35

ILLUSTRATIONS.

	Page.
PLATE I. A sugar beet four months old affected with curly-top	Frontispiece.
II. A healthy sugar beet four months old.....	34
III. Fig. 1.—Leaves from a sugar beet three months old affected with curly-top. Fig. 2.—Leaves from a healthy sugar beet three months old	34
IV. Fig. 1.—Cross section through a vein of a beet leaf affected with curly-top. Fig. 2.—Cross section through a vein of a healthy beet leaf.....	34
V. Fig. 1.—Cross sections of a sugar beet four months old affected with curly-top. Fig. 2.—Cross sections of a healthy sugar beet three months old.....	34
VI. Fig. 1.—Longitudinal section of a sugar beet about four months old affected with curly-top. Fig. 2.—A sugar-beet plant that has apparently recovered from an attack of curly-top.....	34
VII. Fig. 1.—Beets in greenhouse defoliated artificially. Fig. 2.—The same beets shown in figure 1 with new tops four weeks after defoliation.....	34
VIII. Fig. 1.—Garden beets four months old showing symptoms of curly-top. Fig. 2.—Garden beets four months old free from curly-top..	34
IX. Fig. 1.—Sugar-beet field in which nearly all the plants in the foreground have been destroyed by curly-top. Fig. 2.—Field of sugar beets seriously affected with curly-top, showing here and there an apparently healthy beet.....	34
X. Fig. 1.—The fourteenth consecutive crop of sugar beets in a field entirely free from curly-top. Fig. 2.—Sugar-beet plants three months old in pots, showing the effect of various methods of watering.....	34
XI. Fig. 1.—Stem of seed beet affected with curly-top. Fig. 2.—Stem of healthy seed beet.	34

CURLY-TOP, A DISEASE OF THE SUGAR BEET.

SYMPTOMS OF CURLY-TOP.

The external characters or symptoms of curly-top are to be found in all parts of the diseased plant. The leaves that develop after the beets become affected with curly-top are very much smaller and more numerous than normal leaves, and the petioles are very short. The leaf blades are both shorter and narrower than normal leaves and are decidedly crinkled and puckered. (Compare Pls. I and II and figs. 1 and 2 of Pl. III.) On the under side of the leaf blade are many elevations, giving the surface a rough appearance. (Pl. III, fig. 1, and Pl. IV, fig. 1.) The leaves are more or less packed together as compared with a normal beet and the crown is decidedly broadened, as shown in Plates I and II. The roots of beets affected with curly-top are usually hairy, but this character, although nearly constant and distinct, is somewhat variable, being frequently more or less marked than Plate I and Plate VIII, figure 1, would indicate.

In regard to the internal characters or symptoms of curly-top, the tissues of the leaves or leaf stems show a distortion of the cells. (Pl. IV, figs. 1 and 2.) A comparison of figures 1 and 2, Plate V, will show the marked alternation of light and dark rings in the cross section of the diseased root, the fibro-vascular bundles being darkened throughout its entire length, as shown in Plate VI, figure 1. The roots are more or less fibrous or woody and pass through the slicers with difficulty, often causing the knives to clog. There is no decay or softening of the tissue in any part of the plant, except as indicated below.

In addition to the constant symptoms—curled leaves more or less roughened below, thickened crown, hairy roots, dark fibro-vascular bundles, and tough woody roots—there are some other symptoms that frequently accompany the constant curly-top characters, but which are not sufficiently constant to be considered symptoms of curly-top. These may be known as conditional symptoms, since their presence depends upon conditions of growth and environment.

One of these conditional symptoms is the stunted appearance of the diseased beets, which becomes apparent if the disease attacks the beets before they reach their full size. This nondevelopment of the

beets is often looked upon as one of the chief indications of curly-top.^a If the beets are full grown before they are attacked by curly-top they will have all the symptoms of the disease, but necessarily can not be stunted in the sense of being below the normal size. Not only may beets have curly-top without being stunted, but they may be stunted by withholding the water necessary for their development, as shown in Plate X, figure 2, or by subjecting them to other abnormal conditions of growth without producing any of the constant curly-top symptoms.

Curly-top beets sometimes have a wilted appearance as if suffering from lack of moisture. This symptom does not always appear, especially in those cases of curly-top that develop after the middle of the growing season, while in any case the wilted appearance of the leaves is not marked until the season is considerably advanced. Moreover, perfectly healthy beets present a wilted appearance when the interval between rains or between irrigations is too long. The outer leaves wilt first in both instances, but in the case of the diseased leaves the wilting is not necessarily accompanied by a drying out of the soil, and the addition of water will not restore the diseased beets to their normal condition.

Another almost constant character, but one that is not confined to curly-top beets, is the presence of a dark spot in the interior of the crown, as shown in Plate VI, figure 1. A cavity frequently develops in this spot, as shown in the figure referred to. The tissue in the darkened spot does not usually decay, although it becomes somewhat softened and either shrinks or fails to develop with sufficient rapidity, thus forming the cavity. A cavity similar in appearance, apparently due to too rapid growth, forms in healthy beets.

OCCURRENCE OF CURLY-TOP.

Of the various diseases of the sugar beet, two have been more or less destructive in this country for several years. One is the eastern blight, or leaf-spot disease, due to the fungus *Cercospora beticola* Sacc.; the other is the so-called western blight, or curly-top, the cause of which has not been definitely determined. The latter disease only will be considered in this bulletin.

Curly-top has been a subject of observation and study by the writer in the field, in the laboratory, and in the greenhouse for the past six years. It seems to have been known for many years in this country. Doctor Hedgcock, of this Bureau, states that he saw distinct cases of curly-top in garden beets in Nebraska more than twenty years ago.

^a Smith, Ralph E. Beet-Blight Investigation. Report of the Plant Pathologist to July 1, 1906. Bulletin No. 184, California Agricultural Experiment Station, p. 240.

There is no record, however, of a serious outbreak of curly-top until the summer of 1900, when it appeared simultaneously in several widely separated sugar-beet areas in the western portion of the United States. In each of these localities it did considerable damage. Since that time it has been more or less destructive in one or more sugar-beet sections each year.

Curly-top has never been reported with certainty from any other country in which sugar beets are grown, and in this country it seems to be confined almost exclusively to the central and western portions of the sugar-beet belt. It has been studied in Indiana by Arthur, Golden, and Cunningham. It has never been observed by the writer east of the Mississippi River, and while it has been seen in practically all of the sugar-beet States west of the Mississippi River, there are localities in several of these States where sugar beets have been grown for five years or more in which a case of curly-top has never been observed.

Curly-top is not confined to any particular variety of beets. It has been observed on garden beets (red beets) and on stock beets (mangel-wurzels), as well as on all strains of sugar beets. As a rule it is more common, however, on sugar beets than on stock or garden beets. Even in those localities where curly-top is very severe on sugar beets, it has been observed that the stock and garden beets suffer comparatively little from the disease. A striking exception to this rule was found in 1907 in our experimental field at Garland, Utah, in which certain plots of garden beets contained a higher percentage of curly-top beets than could be found in any of our sugar-beet plots in the same field.

Plate VIII shows some of the garden beets affected with curly-top compared with healthy beets from the same row. Curly-top outbreaks are not limited to those sugar-beet areas in which alkali is most abundant in the soil, nor entirely to the irrigated portions of the sugar-beet belt. Curly-top is not usually found in all the fields in any given area, even when it is very serious in that locality. Frequently adjacent fields are attacked by this disease in very different measure. Even a given field is not equally affected in all parts, as shown in Plate IX, figure 1. Furthermore, in the same row beets are not all attacked to the same degree, and frequently we find diseased and healthy plants standing but a few inches apart. (See Pl. IX, fig. 2.)

Young plants seem to be most easily attacked by curly-top, but it is not uncommon for beets that are full grown to develop symptoms of this disease. Sometimes second-year beets that are apparently perfectly healthy when selected in the fall show signs of curly-top during the second season. Its appearance on the stems of seed

beets is strikingly shown in Plate XI. The main stem shown in this plate was trimmed for single-germ seed and then covered with paper and cloth bags in the manner described in Bulletin No. 73^a of the Bureau of Plant Industry, the young shoots showing curly-top that developed under these conditions.

When the outbreak is very serious, new cases occur from day to day or from week to week throughout the season. The large majority of cases developing in any locality during a given season, however, make their appearance before the plants are one-half grown, and frequently more than 50 per cent of the cases found in a given field occur before the beets are a quarter of their normal size.

NAMES OF THE DISEASE.

This peculiar disease of the sugar beet has received so many different names in different localities that considerable confusion has resulted. It has been known as the California beet disease, a bacterial disease of the sugar beet, bacteriosis, bacterial gummosis, blight, western blight, stunted beets, whiskered beets, hairy-root, and curly-top.

Owing to the fact that this disease of sugar beets first appeared to an alarming extent in California, it was called the "California beet disease." This name was soon abandoned, however, as what appeared to be the same disease was found in several other States that year (1900), and since that time it has appeared with certainty in seven of the sugar-beet States. In 1890 Professor Huston, chemist of the Agricultural Experiment Station of Indiana, noticed an abnormal appearance of certain beet samples that he was preparing for analysis.^b These beets were examined by Dr. J. C. Arthur, of the same station, who found large numbers of bacteria in the diseased specimens, and the disease was consequently designated as a bacterial disease of the sugar beet.

In 1891 Miss Golden published the results of her investigation in regard to this and other diseases of the sugar-beet root found in Indiana.^c She isolated an organism found in beets having abnormally curled and twisted leaves and made inoculations into a small number of healthy plants. Four out of six of the inoculated beets developed leaves similar in appearance to the original beets from which the organism had been obtained. It is to be regretted that such a small number of inoculations into healthy plants was made, since this

^a Townsend, C. O., and Rittue, E. C. The Development of Single-Germ Beet Seed. Bulletin No. 73, Bureau of Plant Industry, March, 1905.

^b Huston, H. A. Sugar Beets. Bulletin No. 39, part 2, Purdue University Agricultural Experiment Station, 1892, p. 49.

^c Golden, Katherine E. Disease of the Sugar-Beet Root. Proceedings of the Indiana Academy of Science, 1891, p. 92.

is one of the crucial points in determining the cause of a supposed bacterial disease.

Another report on this disease was published by Professor Arthur and Miss Golden in 1892.^a The presence of bacteria in great numbers in the diseased beet was again verified, but whether they were the real cause of the disease was not clearly established. Some portions of the description and the figures given would seem to indicate curly-top, but the great abundance of the organisms and the ease with which they could be seen and isolated would, on the other hand, seem to distinguish it from the disease which forms the subject of this paper, at least with reference to the cause or causes which produce the curly-top symptoms. Furthermore, Miss Golden states on page 93 of the article above referred to, describing the disease under investigation by her, that "during the early growth of the plants no difference can be seen between the diseased and healthy ones, but as they develop, the outer leaves of the diseased plants wither, while the heart leaves curl up much more than the normal, are dull in color, and the under side has a mottled appearance, causing the leaves to resemble somewhat those of the Savoy cabbage."

According to the writer's observations of the curly-top disease, the center or youngest leaves are the first to show the disease by their curled and puckered appearance. If the disease appears early in the life of the plant all the leaves may be affected, as shown in Plate III, figure 1. The leaves do not usually become dull in color and the outer ones do not necessarily wither or even wilt in the first stages of the disease, although they sometimes wilt and frequently become a few shades duller as the disease progresses. When examined by transmitted light, the leaves of curly-top beets often present a mottled appearance, but this is not usually to be observed by reflected light. Small but distinct elevations, of which no mention is made in the papers cited, are produced on the under surface of the curly-top leaves. (Pls. III, fig. 1, and IV, fig. 1.) Furthermore, no reference is made in these papers to an abnormal appearance of the roots of the diseased beets. In fact, the statement is made regarding what seems for some reasons to be curly-top in Indiana that the healthy and diseased roots can not be distinguished by any external characters. This may be true of the beets that are not affected until late in the season, but the roots of curly-top beets when attacked before the middle of the growing season are decidedly hairy, as shown in Plate I. Curly-top may be a bacterial disease, but certainly it does not seem to be due to an organism so easily seen and so readily separated as that in the disease described by Arthur and Golden.

^aArthur, J. C., and Golden, Katherine E. Diseases of the Sugar-Beet Root. Bulletin No. 39, part 3, Purdue University Agricultural Experiment Station, p. 54.

Dr. Erwin F. Smith,^a in charge of the Laboratory of Plant Pathology, Bureau of Plant Industry, in reviewing the work of Arthur and Golden expressed doubt in regard to bacteria being the cause of the disease of the sugar-beet root described by them and held that the trouble was curly-top. This led to a further study of this disease by Miss Cunningham.^b It was not clearly established by her investigations, however, that the disease found in Indiana is due primarily to bacteria. In summing up the results Miss Cunningham says,^c "Transfers of diseased tissue to the healthy beet root resulted in changed appearance of the plant which indicated almost certainly that the disease was transmitted." This still leaves the bacterial origin of the disease in doubt. Several citations to articles relating to bacterial diseases of the sugar beet were made by Miss Cunningham in connection with the article mentioned.^d

These diseases were referred to by Sorauer^e as "bacterial gummosis," by Kramer^f as "bacteriosis," and by Busse^g as "gummosis" of the sugar beet, but judged by the descriptions given, these diseases do not seem to be curly-top.

Subsequent to the work done by Arthur, Golden, and Cunningham in this connection, Doctor Smith made numerous tube cultures and poured plates from the interior of diseased beets received from the Agricultural Experiment Station of Indiana, but with no definite results. Frequently the cultures were sterile; at other times a variety of organisms was obtained in small numbers, especially if the beets were somewhat wilted. It is evident, therefore, that with our present knowledge of the curly-top disease we should not designate it as a bacterial disease of the sugar beet.

The remaining names of the disease in general use refer to certain characters of the affected plants, and it is largely a matter of judgment which one is most suitable. The names most commonly in use are "blight" and "western blight." Either of these names might be used without confusion were it not for the fact that we have

^a Smith, Erwin F. The Bacterial Diseases of Plants, a Critical Review of the Present State of Our Knowledge. American Naturalist, vol. 30, p. 116, 1896.

^b Cunningham, Clara A. A Bacterial Disease of the Sugar Beet. Botanical Gazette, vol. 28, 1899.

^c Cunningham, Clara A., l. c., p. 188.

^d Cunningham, Clara A., l. c., p. 191.

^e Sorauer, Paul. Note at end of a review of some papers on a disease of sugar cane. Zeitschr. f. Pflanzenkrankheiten, vol. 1, part 6, p. 360, 1891.

^f Kramer, Ernst. Die Bacteriosis der Runkelrube (*Beta vulgaris* L.), eine neue Krankheit derselben. Oesterreichisches Landwirthschaftliches Centralblatt, vol. 1, part 2, pp. 30-36, and part 3, pp. 40-41, 1891.

^g Busse, Walter. Bakteriologische Studien uber die "Gummosis" der Zuckerruben. Zeitschr. f. Pflanzenkrankheiten, vol. 7, pp. 65-77 and 149-155, 1897.

in the middle and eastern parts of our sugar-beet area a true blight of the sugar beet due to the fungus *Cercospora beticola* Sacc. These might easily be distinguished as eastern and western blight of the sugar beet were it not for the circumstance that both may, and often do, occur in the same field in the middle part of the sugar-beet belt.

The objection to the term "stunted beets" lies in the fact that this abnormality may be produced without developing the other symptoms of curly-top; that is, a stunting of the beet may be brought about by causes which do not produce the other symptoms of curly-top, as shown in Plate X, figure 2. "Whiskered beets" and "hairy-root" both refer to the peculiarity of the beet shown in Plate I, in which the small rootlets are very greatly multiplied. While this character is always noticeable on curly-top beets, it sometimes occurs on beets that do not possess the other symptoms of curly-top, and it is therefore undoubtedly produced by some condition that does not cause the development of all the symptoms of curly-top. Furthermore, this peculiarity of curly-top beets is only to be observed when the beets are pulled up. On the other hand, the peculiar appearance of the leaves of beets affected with this disease is noticeable as one passes through a field of beets in which curly-top occurs. The writer has therefore proposed the name curly-top for lack of a better and more characteristic one, which it is hoped will be supplied when the real cause of the disease is known. This character of the diseased plant is easily recognized and, as already pointed out, usually appears during the early life of the plant, but may become apparent in the latter part of the first season's growth or even during the second season.

POSSIBLE CAUSES OF CURLY-TOP.

In different localities and under different soil and climatic conditions curly-top appears sometimes without any apparent cause and sometimes accompanied by parasites or abnormal conditions of soil and climate. Various theories have therefore been advanced in order to account for the occurrence of this disease in the various localities where it has appeared. Among the theories that seemed most plausible because of the conditions and circumstances attending the occurrence of the disease, and which have on that account received more or less consideration, are the following:

- (1) Bacteria.
- (2) Fungi attacking the leaves.
- (3) Fungi infesting the roots.
- (4) Insects.
- (5) Abnormal moisture supply.
- (6) Abnormal soil conditions other than moisture supply.

- (7) Abnormal atmospheric conditions.
- (8) Poor seed.
- (9) A combination of unfavorable conditions.

The following is a brief description of the methods employed and the results obtained in studying these possible causes of curly-top.

BACTERIA.

The symptoms of curly-top as already described suggest at first the presence of some parasite as the cause of the disease. The writer has made many attempts to prove or disprove the bacterial theory of curly-top. Nutrient agar plates have been poured from different parts of diseased beets of different ages and under different conditions of growth. In only a few cases has an organism been isolated, and such organisms have not induced the symptoms of curly-top with certainty in any case, as already stated on page 11. Inoculations have been made into various parts of healthy beets of different ages and under field as well as greenhouse conditions.

It might be argued that the organism was not capable of growth on the culture media used, and therefore could not be separated in the usual way. With this possibility in mind, pieces of tissue were cut from different parts of distinctly diseased beets and inserted into incisions made in healthy beets of different ages and under different conditions of growth, but always with negative results under the conditions employed.

FUNGI.

FUNGI ATTACKING THE LEAVES.

The general appearance of curly-top beets indicates a more or less starved condition of the plant, although a chemical examination of the diseased plant does not show an absence of the necessary food material. It is possible, however, that the cells of the diseased plant are incapable of utilizing the material that it has taken up. This led to the theory that the leaves might for some reason fail to perform their proper function and thus the whole plant become starved.

One of the most serious natural injuries that has been observed as occurring on beet leaves is that produced by the fungus *Cercospora beticola* Sacc. Pure cultures of this fungus were obtained and the spores were sprayed upon healthy leaves until they became as thoroughly infested with the fungus as possible. No symptoms of curly-top appeared in any of the beets thus treated, either immediately after treatment or during any subsequent growth of the plant. Likewise in the fields where *Cercospora* was most prevalent, no cases of curly-top have been observed, even when the plants were almost entirely defoliated by the fungus.

In order to carry the theory of leaf injury to the farthest limit, several hundred sugar beets growing in the greenhouse had their leaves removed and were left otherwise undisturbed. (Pl. VII, fig. 1.) New tops were rapidly formed, all of which were in every respect perfectly normal. (Pl. VII, fig. 2.) The treatment was repeated in the field in the West, where curly-top has frequently been found. Some of the rows of beets selected for this purpose were entirely defoliated several times by means of a sharp knife with no apparent result except a marked retardation in the growth of the beets. Finally, in those localities where curly-top is most prevalent, the beet leaves suffer least from attacks of fungi and the atmospheric conditions are most favorable for the performance of the life functions of the leaf. If curly-top is due to any changed condition of the leaf, that condition is not induced by a reduction of the leaf surface or by the inability of the leaf cells to perform their normal functions.

FUNGI ATTACKING THE ROOTS.

In certain parts of the sugar beet area where curly-top is found more or less frequently, the soil is sometimes permeated with a fungus that grows close to the main root of the beet, often matting the fibrous or feeding roots together. This fungus often forms in the soil a network of white filaments easily seen with the unaided eye. Pure cultures of the fungus, which proved to be a species of *Fusarium*, were obtained in the laboratory. The same fungus was found in fields containing diseased roots in widely separated areas, even from different States. Inoculations were made with this fungus, beets of different ages from seedlings with only two leaves to plants two-thirds grown being used. These inoculations were made both in the greenhouse and in the field. In some instances the fungus was simply placed in contact with the healthy root, and with other plants incisions were made in the roots and the fungus placed in contact with the cut surfaces; but in none of the artificial inoculations did the fungus seem to penetrate the tissues of the beets, and no symptoms of curly-top were produced in any of the plants inoculated.

A quantity of soil was obtained from one of the fields where curly-top prevailed in 1905, and this has been used for two years in growing sugar beets in the Department greenhouses at Washington under a great variety of moisture and temperature conditions. In some instances the moisture has been applied to the surface of the soil only; in other cases the seed and resulting plants have been watered only from below. Some of the plants have been given an abundance of moisture, while others have received just sufficient to keep the soil barely moist enough to keep the plants active. The temperature has varied from 85° F. to 50° F., some of the plants remaining con-

stantly at a high temperature, others at a low temperature, and still others at an intermediate temperature. It is noticed that if the soil is allowed to become somewhat dry the fungus appears among the soil particles and around the roots of the plants, but in all of these experiments the only result noticed was a difference in the size of the plants. In no case were curly-top symptoms induced in any of the plants grown in this soil under the conditions used.

It should be added that the same fungus is often apparent in the soil, and even in contact with the beets, in fields where not a single case of curly-top can be found. Nevertheless, there may be conditions under which this or some other fungus in the soil may affect the beets directly or indirectly in such manner as to produce curly-top. In support of this theory is the fact that the writer has in a few instances found the mycelium of a *Fusarium* fungus actually growing into the tissue of the small roots of diseased beets. It can not be stated positively, however, that the disease is caused by a fungus until the disease can be produced at will by inoculations made from a pure culture of that fungus.

THE USE OF FUNGICIDES.

The fact that a fungus is found so frequently in connection with curly-top and that in a few instances a fungous mycelium has been found in the tissues of diseased beets has led to certain experiments with fungicides. The substances used were corrosive sublimate and copper sulphate. Solutions of different strengths were made and the roots of distinctly diseased beets were soaked in these solutions for different lengths of time.

The copper sulphate solution first used consisted of 1 part of copper sulphate in 3,000 parts of water by weight. One lot of beets was soaked in this for two minutes and another lot was soaked for five minutes. When removed from these solutions, the roots were all rinsed in distilled water. Upon examining these roots the following day, it was found that the fungus was not dead. The two lots of roots were again soaked for two minutes and five minutes, respectively, in the copper sulphate solution, 1 part of copper sulphate in 1,000 parts of water being used. This seemed to kill the fungus, and the beets were planted in 6-inch pots in the greenhouse.

The mercuric chlorid solution consisted of 1 part of mercuric chlorid in 1,000 parts of water by weight. One lot of beet roots was soaked in this solution two minutes and another lot was soaked five minutes, and both lots were then planted in 6-inch pots in the greenhouse. For comparison, a fifth lot of diseased beets was planted in 6-inch pots in the greenhouse without any treatment. A number of beets in each lot, including the controls, began after several weeks to

present leaves with broader and smoother leaf blades, and in from three to four months the leaves were normal in shape. Some beets in each lot, including all treated lots, retained the curly-top symptoms, although the fungus could not be found again upon the treated beets.

It has been observed repeatedly that beets with distinct curly-top symptoms frequently recover to all appearances when kept for several weeks under normal greenhouse conditions, while others under similar conditions retain the symptoms of curly-top for months. In the vicinity of Washington, D. C., the treatment with fungicides would indicate that the destruction of the fungus growing in contact with the beet does not influence the recovery of diseased plants.

It is not to be assumed that the foregoing treatments with fungicides are considered practical, even if they caused the diseased plants to recover. The experiments were undertaken wholly for the purpose of shedding light upon the possible relation of a fungus to the disease under investigation.

INSECTS.

Frequently curly-top is associated with some insect pest. This occurrence often leads the grower to the conclusion that the insect most prevalent upon the diseased beets is the cause of the disease. While one of the many insect pests that infest growing beets may be responsible for the disease, in the opinion of the writer this has not yet been demonstrated beyond doubt, although Doctor Ball, Director of the Utah Agricultural Experiment Station, who has done considerable work on this subject in cooperation with the Bureau of Entomology, holds that the so-called "white fly" is the cause of curly-top.^a

Frequently the curling of the leaves of curly-top beets seems to be due to a failure of certain portions of the leaf tissues to develop beyond a certain stage, as shown in the younger leaves in Plate III, figures 1 and 2, while certain other leaf cells seem to make an abnormal growth, causing the development of projections on the lower leaf surface, as shown in sections of leaves in Plate IV, figure 1. Whether or not these and other abnormal characters of curly-top beets are due in any way to the work of insects can only be determined by further investigations.

^a Ball, E. D. The Genus *Eutettix*. Proceedings of the Davenport Academy of Sciences, vol. 12, pp. 41 and 84 and plate 4, July, 1907. The Beet Leaf-Hopper, 16th Annual Report, Utah Agricultural Experiment Station, June, 1905, p. 16.

ABNORMAL MOISTURE SUPPLY.

ENTIRE SEED BED TOO DRY.

If one studies the curly-top disease in a restricted locality for a single season he will almost certainly be misled in his conclusions. With reference to no conditions attending the appearance of curly-top is this more generally true than with the moisture condition of the soil. In some localities where curly-top has been especially prevalent during certain seasons the seed bed has been particularly dry, so that the seeds germinated slowly and unevenly and the seedlings started with difficulty. As all other conditions so far as observed seemed favorable, it was fair to conclude that this one unfavorable condition was responsible for the diseased condition of the beets. However, if one continues his observations in another locality or into another season he will find cases of curly-top in fields where the moisture conditions were entirely favorable for germination.

In order to investigate this point still further, greenhouse experiments were conducted in which the minimum amount of moisture was used to germinate the seed, with the result that the seed was slower in germinating, but the seedlings, if given a sufficient supply of water, grew normally. If only a minimum amount of water was given the seedlings, they remained abnormally small, but otherwise showed no symptoms of curly-top. (Pl. X, fig. 2.)

INSUFFICIENT SUPPLY OF MOISTURE AT TAPROOT.

During the first few years in which curly-top was most destructive it occurred only in those localities in which there was a scarcity of moisture, and the diseased beets had the appearance of plants suffering from a lack of moisture. This led several observers, including the writer,^a to arrive at the conclusion that curly-top is due to a lack of moisture at the taproot of the beet. Subsequent observations in the field and carefully conducted experiments in the greenhouse have demonstrated that whatever may be the cause of curly-top it is not lack of moisture alone.

In order to demonstrate more conclusively the effect of an insufficient water supply, a number of seedling beets were started in the greenhouse in large pots of earth. Some of these plants were given a sufficient quantity of water so that they were constantly supplied with moisture, some being watered entirely from below so that the taproot was constantly supplied, while others had the water applied only to the surface of the soil. Still a third set of plants started at

^a Townsend, C. O. Some Diseases of the Sugar Beet. Report No. 72. United States Department of Agriculture. Progress of the Beet Sugar Industry in the United States, 1901, p. 90.

the same time and under identical conditions received only enough moisture to keep them alive, and this was applied to the surface of the soil, the object being not to give sufficient water at a time to permit it to soak down and moisten the soil around the taproot. The results are shown in Plate X, figure 2, in which the dwarf plant (C) received only enough water to keep it alive. The leaves were normal except in size and the roots showed none of the curly-top symptoms.

ENTIRE SEED BED TOO WET.

The observations of recent years seem to prove that too much moisture during the early part of the season might possibly be responsible for the appearance of curly-top. However, a series of observations in different localities shows that a wet seed bed may do considerable damage to the stand by causing the seed to rot and the seedlings to damp-off, but this is not necessarily accompanied by curly-top.

Greenhouse experiments along the same lines have demonstrated that an excess of moisture during the early life of the plant will not produce the disease. Likewise, a very wet seed bed not followed by the addition of moisture either in the form of rain or artificially applied does not, according to the observations made by the writer, insure freedom from curly-top in all cases. The distribution of diseased plants in the field, scattered as they frequently are here and there among the healthy beets, would prove that a seed bed too wet could not alone be responsible for the occurrence of diseased plants. Dr. Wilhelmj^a is of the opinion that curly-top is closely connected with water supply, but this point does not seem to have been established by actual experiment and, as has already been indicated, one may reach almost any conclusion by extending or limiting his observations.

MOISTURE SUPPLY TOO VARIABLE.

In some of the irrigated sections where a limited amount of water is divided among a large number of growers, it sometimes happens that too much time elapses between the irrigations, so that the beets suffer for a longer or shorter period from lack of moisture. When the water is obtained the beets are given as much moisture as the ground will hold with the hope of being able to keep them supplied until water can be obtained again from the ditch. Under these conditions curly-top has sometimes appeared.

In order to determine the relation of variable moisture conditions to this disease, beets have been made to pass through their extremes

^a Wilhelmj, A. Eine Eigenartige Rübenkrankheit. Zeitschrift des Vereins der Deutschen Zucker-Industrie, April, 1907.

of moisture and drought, the wet and dry conditions being carried farther and for a longer period in the experiment than in actual practice. The results have been only dwarfed plants without any curly-top symptoms. These experiments, combined with many field observations of beet growing in which there was great variation in moisture supply, sometimes entirely unaccompanied by curly-top, lead to the conclusion that this condition alone is not sufficient to produce the disease.

WATER TOO COLD WHEN APPLIED TO PLANT.

Since irrigation streams are frequently supplied with large quantities of water produced from melted snow, especially in the early spring, and since the young plants are most frequently affected with curly-top, the theory has been advanced that the early irrigation waters are too cold. It is difficult to understand how cold water could induce curly-top in a few beets here and there throughout a field, and yet it is not impossible when we consider the individuality of the beet. It is likewise difficult to explain under this theory the late cases of disease that appear in the middle and latter part of the summer.

However, in order to dispel all doubt in regard to the matter several series of beets were started in the greenhouse, and as soon as the seedlings appeared they were watered with ice water only. In some of the experiments the plants were watered with ice water every day or every two days, while in other experiments the interval between waterings was longer. These experiments were continued for several weeks without producing any curly-top symptoms.

It might be added as further evidence against this theory that one field which has been under the writer's observation for the seasons of 1905 and 1906 is irrigated with water from warm springs, yet each season a few cases of curly-top have appeared. Hence, cold water applied at any time during the growth of the plants is not the primary cause of curly-top.

ABNORMAL SOIL CONDITIONS.

SEED BED TOO COLD.

It is well known that a damp, cold seed bed has a marked influence upon the germination and growth of plants. There is a strong desire on the part of seed growers to plant their seed as early as possible, so as to give the plants a long season to grow and also to be able to harvest the beets before cold weather sets in. This practice sometimes leads the growers to plant before the ground is warmed to a normal planting temperature. While this condition has not always preceded an outbreak of curly-top, it has sometimes been associated

with it, so it was decided to test the effect of a cold seed bed upon the growth of beets. Accordingly, an air cooler was installed in a small room in which the temperature could be controlled within certain limits. Boxes of soil were placed at different distances from the cold-air generator and also at different distances from the floor, and the soil was maintained at such temperature that germination and growth proceeded with difficulty. An insufficient supply of light in the room used for the work prevented the experiment from being entirely satisfactory, but during the several weeks that the plants lived they showed no signs of producing curly-top symptoms.

SEED BED TOO WARM.

The fact that the later plantings are the ones that are occasionally most severely attacked by curly-top raised the question with some growers as to the possibility of a too warm seed bed being the cause of the disease. In considering all the conditions under which curly-top is produced, especially the frequency of the disease in seed beds that are not above normal temperature, one must conclude that excessive warmth of the seed bed does not produce curly-top.

To test artificially the effect of an abnormal temperature, some seedling beets growing in pots of earth were placed near the furnace, where the temperature which was recorded daily from a maximum and minimum thermometer varied between 72° and 104° F. While the plants made very little growth, owing to the excessive heat, they showed no signs of curly-top even after several weeks.

SUBSOIL TOO HARD.

In some localities where curly-top has appeared, a hard subsoil has been found to exist so close to the surface of the ground that the beet roots grow down and come into contact with it without being able to penetrate it. This condition does not obtain in all places where curly-top has been found. Indeed, the disease frequently occurs in localities where the soil is of a rich loamy nature to the depth of several feet. Furthermore, in many localities where there is a hardpan underlying a shallow soil, beets grow without developing curly-top. The beets produced under these conditions may be dwarfed, they may extend abnormally out of the ground, or they may have sprangled roots, but these abnormalities do not necessarily accompany curly-top.

LACK OF AVAILABLE PLANT FOOD IN THE SOIL.

The apparent inability of curly-top beets to grow even where temperature and moisture conditions are known to be normal led some of the growers to assume that curly-top is due to a lack of avail-

able plant food in the soil. The inability of the badly diseased beets to grow would indicate either that the diseased plants were unable to take in the necessary plant food from the soil, from the atmosphere, or from both of these sources, or that having absorbed the necessary food material the plants were unable because of their diseased condition to assimilate it.

Experience has shown that plants growing in poor soil are no more susceptible to curly-top than those grown in rich soil. Further proof of the incorrectness of this theory is found in the fact that fields in which beets are utterly destroyed one season will without the application of any plant food produce a good yield and quality of perfectly healthy beets the following season. This has been demonstrated in actual practice under the writer's observation every season during the past six years. In one locality several thousand acres of beets were entirely destroyed by curly-top in 1903. The following season a large part of this area was replanted, and in every instance a most satisfactory crop of beets was obtained, the most diligent search failing to reveal a single case of curly-top. Many of these fields received no special treatment for the crop of 1904, and if there had been a lack of plant food during the season when the disease was prevalent it is fair to assume that there would have been the same lack of available plant food the following season. Again, a lack of available plant food would not affect 50 per cent of the beets in a field and leave the remaining ones perfectly healthy, especially with the two kinds scattered about over the entire area and standing, as they frequently do, within 8 or 10 inches of each other.

Plate X, figure 1, shows the fourteenth consecutive crop of beets on the same field without a single case of curly-top. Furthermore, sugar beets are frequently grown on soils that have become apparently exhausted by numerous grain crops; but it is very seldom that any cases of curly-top are found in these fields. Curly-top may be due to a starved condition of the beets, but if so the trouble is with the beet and not with the soil in which it grows.

LACK OF HUMUS IN THE SOIL.

The two main sources of humus for the irrigated lands of the West are stable manure and alfalfa. The small amount of stable manure produced as compared with the large area to be supplied with humus makes it impossible to obtain enough humus from this source to put the soil in the proper physical condition. Formerly it was customary with many farmers to let the alfalfa fields remain undisturbed for a long series of years if they continued to furnish a paying quantity of alfalfa. Under such conditions many of the other cultivated field

crops suffered for want of humus, and the same conditions prevail in some localities at present, though many farmers now use alfalfa as a rotation crop, plowing it under after only three or four years. However, the scarcity of humus, especially in earlier years, has sometimes been associated with curly-top, a circumstance which led to the advancement of the theory that the scarcity of humus was the cause of the disease.

Observations of more recent years have tended to discredit this theory. For example, in some of the extensive wheat-growing areas of the West it has sometimes been customary to grow wheat after wheat for a number of years, in some cases even until the yield was no longer profitable. During these years of wheat growing, frequently no humus was added to the soil except the small amount furnished by the stubble. If, now, beets are grown in this soil the first crop will be poor; that is, the beets will be small but no curly-top will necessarily appear. The second crop of beets will be better than the first, and the third crop will be better than the second, even without the addition of any humus, but in no case will there be any curly-top that can be attributed to the lack of humus. On the contrary, curly-top has been found in more recent years just as frequently in fields well supplied with humus as in those that are deficient in this material. Furthermore, the fact that beets will thrive without the addition of humus in fields where they were entirely destroyed the previous season by curly-top is proof that the lack of humus alone is not the cause of this disease.

TOO MUCH ALKALI IN THE SOIL.

Many growers of beets in the more alkaline regions have associated curly-top with the presence of alkali. It is well known that the amount of alkali in certain layers of the soil varies from season to season and from time to time during the same season. Without any means of determining the amount of alkali in the soil it was assumed that the alkali was especially abundant in those spots or localities where the disease appeared. More recent observations have shown that the soil may contain a sufficient quantity of alkali to kill the plants without producing curly-top, and even if the quantity of alkali present is not sufficient to destroy the life of the plant, but only to interfere with its normal functions, a dwarfed plant will result, but none of the curly-top symptoms is necessarily produced. On the other hand, curly-top has been frequently observed in localities where an abnormal amount of alkali is not present at any time during the season.

Several series of greenhouse experiments were conducted to supplement the field observations in regard to alkali in relation to curly-

top. In these experiments sodium chlorid and sodium carbonate solutions were used. The solutions were made up in four strengths, namely, 1 part of the salt to 1,000 parts of water, 1 part of the salt to 500 parts of water, 1 part of the salt to 100 parts of water, and a saturated solution.

The plants treated varied from seedlings 2 weeks old to beets 10 weeks old. With the seedlings, 10 c. c. of the solution were applied at a time; with the older plants, from 20 to 50 c. c. of the solution were given each beet at each application. The dilute solutions were applied to the plants daily for thirty-two days. Some of the plants died, while others remained alive, but assumed a yellowish tint without showing any signs of curly-top. The seedlings that received the saturated solutions all began to wilt within thirty minutes after the solution was applied. Several of the plants died without showing any tendency to recover, while others began to revive in from five to seven days and continued alive for several weeks with the appearance of normal beets. In the case of the older plants, the dilute solutions made no appreciable difference in their appearance or growth, while the saturated solution caused the leaves to assume a slightly paler tint, but in no case did the characteristic symptoms of curly-top develop.

SOIL TOO ACID.

While the Bureau of Soils was making a survey of one of the important sugar-beet localities in California in 1901,^a certain observations were made regarding the relation between the acidity of the soil and the blight, or curly-top. It was noted by Messrs. Lapham and Heileman, who had direct charge of the survey of the area mentioned, that many of the soils in the valley under observation were either neutral or slightly acid and that few of the soils showed even a slight effervescence with hydrochloric acid, indicating either a very small amount of carbonate of lime or none. They observed further that the soil was acid in those fields where the disease occurred in that locality and that the disease did not occur in this locality in any soil that was alkaline to litmus. These observations naturally led Messrs. Lapham and Heileman to the conclusion that the deficiency of lime as carbonate gives rise to a neutral or slightly acid condition of the soil, which is a very important, if not the most important, factor in the cause of beet blight, or curly-top. As indicated, however, under the preceding theory, an alkaline condition of the soil does not prevent attacks of curly-top. Field observations and experi-

^a Lapham, M. H., and Heileman, W. H. Field Operations of the Bureau of Soils, Department of Agriculture. Soil Survey of the Lower Salinas Valley, California, 1901, p. 506.

ments indicate that applications of lime, whether light or heavy, will not prevent curly-top. It is possible, however, that under some circumstances an acidity of the soil may be a factor in producing curly-top.

IMPROPER PREPARATION OF THE SEED BED.

A properly prepared seed bed is one that is plowed at the right time, under proper conditions of moisture, and to the correct depth without turning up too much raw soil. It must be worked at such time and in such manner as to conserve the moisture and to produce a firm seed bed below, with a fine mulch about $1\frac{1}{2}$ inches thick on the surface. Owing to the many conditions to be fulfilled in properly preparing a bed for beet seed, it is not surprising that in many of the fields in which curly-top has appeared one or more of these conditions have not been fulfilled. This was especially true several years ago, before beet growing was as well understood as it is at the present time.

This theory was suggested by the appearance of curly-top in certain fields, while in other fields in the same locality differently prepared to receive the seed, the disease was absent. More extended observations and experiments teach us that plants growing in the most thoroughly prepared seed bed are sometimes seriously affected with the disease. Again, the distribution of the diseased plants in the field, as previously mentioned, contradicts this theory.

IMPROPER CULTIVATION OF THE BEETS.

This may include both the time of cultivation and the method employed. It is generally conceded that cultivation should be begun as soon as the rows can be followed, but in regard to the depth of cultivation and the distance that the cultivator teeth should be kept from the plants there is considerable difference of opinion among beet growers. One of the strongest arguments against the belief that lack of cultivation may be a cause of the disease is to be found in the abandoned or neglected beet fields which one occasionally finds here and there in different parts of the sugar-beet belt, inasmuch as these abandoned fields are frequently free from curly-top. If the method of cultivation is a factor in producing the disease, it is presumably because of the injury to the side roots due to deep or close cultivation or to both deep and close cultivation. We find that deep and close cultivation are practiced just as frequently in the areas where curly-top has never appeared as they are in those areas where the disease has been most destructive.

By way of experiment a number of beets of different ages were injured by cutting the side roots with a large knife. The results so far as curly-top is concerned were negative.

The first operation in caring for the beets after they are up is that of thinning. It is well known that any delay in performing this operation will result in a decrease in the yield of beets to the acre, but so far as can be ascertained by field observations and greenhouse experiments the delay does not produce any of the symptoms of curly-top.

INSUFFICIENT SUPPLY OF AIR AROUND THE ROOTS.

It is well known that the roots of land plants must receive a sufficient quantity of air in order to produce a normal growth of the plant. The appearance of curly-top in many fields where a crust had formed on the surface of the soil led some observer to think that this disease might be due to a lack of air around the roots. A study of curly-top in other localities established the fact that the disease is not confined to those fields where a crust has formed on the surface, nor even to those localities where the soil is of such a nature that the crust forms readily under the conditions that prevail during the early life of the plants.

In some instances curly-top has appeared in localities where there was an excessive supply of moisture in the early part of the season. This led to the suggestion that too much moisture at the taproot, if continued for some time, might produce curly-top by cutting off the air supply. In some of the many sections of the sugar-beet area certain seasons have been excessively wet. Some fields not properly drained have been for a number of days under water. This abnormal condition, if of sufficient duration, invariably results in a weakened condition of the beets, as indicated by the yellow color of their leaves, a state from which they may eventually recover to a considerable extent if normal conditions are restored and allowed to continue. In no case where these excessive rainfalls have occurred and abnormally wet conditions have prevailed for several weeks have any symptoms of curly-top been observed.

Curly-top usually occurs in the irrigated sections, where the danger of excessive moisture is, of course, at a minimum. In the greenhouse this abnormally wet condition of the taproot has been repeated with plants of different ages and at different temperatures with similar negative results. As already pointed out, curly-top often appears in those fields where the soil is well drained and under thorough cultivation and thrives where the conditions for a proper air supply are best. While a lack of air around the roots may be a secondary factor in producing curly-top, it certainly is not the primary cause of this disease.

ABNORMAL ATMOSPHERIC CONDITIONS.

ATMOSPHERE TOO COLD AT TIME OF GERMINATION.

The experiment just described served also to illustrate the effect of a cold atmosphere upon the young beet plants. Aside from retarded growth, no abnormal symptoms were observed. Frequently in the field one finds that the desire to plant early leads to the production of seedling beets before the cold nights are over, so that the young plants are subjected to extremes of temperature. While these conditions have sometimes been followed by a more or less severe outbreak of curly-top, there have been so many exceptions that one is led to the conclusion that no relation exists between curly-top and the cold atmosphere.

HOT, DRY WINDS.

In many fields where curly-top appears, windbreaks are to be found along one side of the field. These windbreaks may consist simply of a fence, or of a row of trees, or of a field of grain. It has been frequently observed that the beets growing close to the windbreak, and therefore most completely protected from winds, are least affected by curly-top. (Pl. IX; fig. 1.) These observations lead to the theory that hot, dry winds blowing over the beet fields, as they often do nearly every day at certain hours in some localities, induce the disease.

In order to produce as nearly as possible the same conditions artificially, a number of seedling beets were started in pots in the greenhouse, and when firmly established were placed in the laboratory engine room, where the heated air from the boiler could be blown over the plants. This was accomplished by arranging an electric fan on the same level with the plants and allowing the fan to blow the hot air from the boiler over them for several hours each day. The plants were supplied with an abundance of moisture and all other conditions were normal, except that the light was not as intense as it would have been in the open. Several sets of plants were treated from two to four weeks in the manner described. Some of the plants died, presumably from the treatment, but in no case did any symptoms of curly-top appear, either during the treatment described or during the subsequent life of those plants that were returned to the greenhouse alive. Therefore, the experiments thus far conducted along this line indicate that hot winds alone are not the cause of curly-top. At the same time it is difficult to explain why it is that the healthier beets are frequently found in the more protected localities. One exception to this general rule was observed during the summer of 1906 on the Department experimental farm at Amarillo, Tex. About one acre

of beets was grown for experimental purposes, and that part of the plot best protected from the prevailing winds by a plot of sorghum contained many specimens of curly-top.

POOR SEED.

More frequently than any other one factor in sugar-beet growing, the quality of the seed has been held responsible by the growers for the outbreaks of curly-top. Many of the men who hold to this theory have no definite idea in regard to what constitutes the particular poor quality of the seed that causes curly-top to develop. Some growers, however, believe that there is in some seeds an inherited tendency toward the disease, while others maintain that small or poorly developed seeds produce weak plants that are unable to grow in a normal manner and are therefore easily attacked by disease.

Whatever view is held in regard to the details of this theory, the distribution of the diseased plants in the field—a badly diseased plant often standing within a few inches of a perfectly healthy one—would tend to support the poor-seed theory. On the other hand, we find a number of circumstances that appear to render this theory impossible. In 1903 curly-top destroyed 50 per cent of the beets in a certain locality, and the seed used was a part of a shipment the remainder of which was used, according to good authority, in two other localities. In the second and third localities where this seed was used practically no curly-top developed. It should be further noted that some fields in the badly diseased locality were entirely free from curly-top, although they were planted with seed from the same shipment. If all fields and all localities in which this seed was used had been equally affected we would have strong proof of the poor-seed theory.

In 1904 certain fields reported to have been planted from the same sack of seed were variously affected, some being very badly diseased and others practically not at all. If curly-top is due to the quality of the seed, it would be difficult to explain why some seed beets show curly-top symptoms during the second year's growth when they were to all appearances perfectly healthy during the first season of their existence.

In experiments with small seeds as compared with large ones, the plants in both cases have been equally free from curly-top. In these experiments it must be remembered that the size of the seed ball does not indicate the size of the individual seed. This latter point can be determined only by close examination of the seeds to be used.

Finally, the same quality of seed is generally used in different parts of the sugar-beet area. If curly-top is due to inferior seed it will be necessary to find some explanation for the entire absence of curly-top

in certain portions of the sugar-beet area. Whatever the cause of curly-top may be, the bulk of the evidence indicates that the quality of the seed is not the primary factor in its development.

COMBINATION OF UNFAVORABLE CONDITIONS.

Negative results in matters like the foregoing are conclusive only so far as they relate to existing conditions and circumstances, and it must be remembered that under other conditions the same agent or factor might give positive results. Therefore, it can be stated with certainty only that the factors discussed are not responsible for curly-top under the circumstances and conditions under which the observations and experiments were made; that is, there may be conditions not yet investigated in which the fungus, for example, may produce the curly-top symptoms. Or it may be that some fungus other than the one isolated may yet be found to be responsible for the disease. In considering the possible factors that might cause curly-top, many combinations of unfavorable conditions have been suggested and many of them have been investigated. In this connection the theories mentioned may conveniently be considered under the following groups, namely: Parasites, soil conditions, weather conditions, cultural conditions, and seed.

The bacterial and fungus parasites isolated have been tested; that is, inoculations have been made into healthy beets of different ages, from seedlings a few days old to beets one-half to two-thirds grown. Both field and greenhouse conditions have been tried; the field conditions under various methods of irrigation, the greenhouse conditions under different degrees of temperature and moisture. Various combinations of soil conditions have been made, dry and moist soil being used at temperatures varying from 80° F. to 50° F. Dry and moist soils were combined with hot, dry winds, and consequently hot, dry winds were combined with dry and moist soils. The same seed was tried under different conditions of soil with respect to dryness and moisture, with respect to alkalinity and acidity, and with respect to temperature and time of planting. In none of the combinations of unfavorable conditions that have been tried have any indications of curly-top traceable to these conditions been produced. It is entirely possible that some combination of conditions will be found that will produce the curly-top symptoms. However, the matter does not seem as simple to the writer as it is expressed by Doctor Wilhelmj ^a when he says the beets do not become diseased whether they have a great deal of moisture or none at all in the form of rain during the first part of their growing period, but that they do

^a Wilhelmj, A., l. c., p. 432.

become diseased if a hard rain falls after a period of drought. It is undoubtedly true that the digestion of curly-top beets has become abnormal, as Doctor Wilhelmj states,^a but the cause of this disturbance has, in the writer's opinion, not yet been established.

NONCONSECUTIVE APPEARANCE OF CURLY-TOP.

One of the most important facts in regard to curly-top is that it very seldom appears two consecutive years in the same locality. During the six years that this disease has been under observation by the writer it has been destructive during two consecutive years in but one locality, and in this case the relative number of diseased beets was not nearly so great the second year as it was the first. In general, it may be said that the appearance of curly-top in a given locality one season does not in any way endanger the crop for the following year. As previously stated, the locality in which curly-top was so destructive in 1903 had an exceptionally good crop in 1904, practically no cases of curly-top being found even in the fields in which the beets were entirely destroyed the preceding year.

BEETS RESISTANT TO CURLY-TOP.

The distribution of healthy beets among diseased ones in many badly infested fields, as shown in Plate IX, figure 2, would seem to indicate that certain beets are resistant to curly-top. For the purpose of breeding plants resistant to this disease, several hundred healthy beets were selected and siloed. Care was taken to find healthy beets that were growing close to badly diseased ones, so that in case of possible communicability of the disease we would have those that were unmistakably resistant. Selections of this kind were made in different localities in 1902, 1903, and 1904. In each case the siloed beets came through the winter in good condition for planting, and very nearly all of them produced seed which was of good quality. The difficulty in determining whether or not the seed would produce beets resistant to curly-top was found in the fact that it is impossible to predict where the disease will occur in any given season. It has never been serious in more than three or four localities at one time, and these more or less restricted; and the fact already pointed out that it practically never occurs two years in succession in the same locality makes it impossible to know where to grow the beets to determine whether or not they are resistant to curly-top. Even if we knew in what locality the disease would occur, the fact that adjacent fields or different parts of the same field are affected to very different degrees so far as the appearance of the disease is concerned would still render the problem impossible of solution from this standpoint. Again, it would seem that plantings made in any locality just as soon

^a Wilhelmj, A., l. c., p. 435.

as the disease makes its appearance ought to help in determining the resistance of plants; but observation has shown that plantings made with the same seed, but a few days before or after certain badly diseased fields were planted, are frequently but slightly if at all affected with curly-top.

At one of our sugar-beet stations where a quantity of seed selected for curly-top resistance was planted along with twenty-five other varieties and strains, some curly-top beets were found in each plot. This seed was all planted on April 22, 1907, and each plot received the same treatment throughout the season. At the end of the growing season a careful count of all the curly-top beets found among each of the twenty-six varieties and strains grown on equal areas showed that for every 10.7 beets affected with curly-top found among those grown from seed selected for curly-top resistance there were from 22 to 124 among the other twenty-five varieties and strains not selected for resistance. A large number of selections were made from the plot that indicated curly-top resistance, and this strain will be perpetuated and improved with a view to making it entirely resistant to curly-top.

COMMUNICABILITY OF CURLY-TOP.

All evidence thus far obtained is against the transmission of curly-top from plant to plant by any known means. In the field we find beets badly diseased growing side by side with others to all appearances perfectly healthy. It is not uncommon for this condition to exist throughout the season. Furthermore, several instances have been observed by the writer in which two plants have been found growing in close contact with each other, one showing all the symptoms of curly-top and the other presenting a perfectly normal appearance. This state of contact continued throughout the season without developing any curly-top symptoms in the healthy beet. Bits of tissue have been cut from diseased beets and inserted in incisions made in different parts of healthy beet roots, but in no case has curly-top developed under the conditions used. No definite conclusion can be reached regarding the point, however, until the exact cause of curly-top is known.

PERSISTENCE OF CURLY-TOP.

In almost all cases, beets that have become unmistakably affected with curly-top either die from the effects of the disease before the end of the season or, if the beets continue to live throughout the season, as they frequently do unless the outbreak is very severe, the curly-top symptoms remain apparent. No amount of special attention seems to be effective in restoring the diseased beets to a normal condition so long as they remain in the field where they were first attacked. In

some instances if they are taken up and removed to some other soil they seem to recover after several weeks, so far as the appearance of the leaves is concerned. Thus, a badly diseased beet transplanted to a greenhouse of the Department of Agriculture in August, 1902, was photographed six months later, showing the flat leaves commonly found on healthy beets. (Pl. VI, fig. 2.) This change does not always take place, however, even when the beets have been placed under different climatic conditions and transplanted into entirely different soil.

Some badly diseased beets planted in the greenhouse in August, 1905, still retained their curly-top symptoms even at the end of eight months. If the diseased leaves are removed the new set produced shows all the leaf symptoms of curly-top. If the new set of leaves is in turn removed the third set may be as badly affected as the first or second, as demonstrated by repeated experiments in the greenhouse and in the field. If the beets are left in the field and given special attention in the way of irrigation, cultivation, etc., the curly-top continues to develop in the same way and to the same extent as in the adjacent rows where the beets have received no special attention.

SUMMARY.

Curly-top is not identical with any disease of the beet previously described, except possibly that described from Indiana.

It is a distinct disease with well-marked symptoms.

It has not been reported with certainty from any country other than the United States.

It has thus far been confined to the middle and western parts of this country.

It is capable of appearing under a great variety of soil and climatic conditions.

It does not seem to be produced by any one abnormal condition of soil or climate.

It does not seem to be due to any parasite isolated thus far.

It does not seem to be due to the condition of the seed.

It attacks stock and garden beets as well as sugar beets.

It is not limited to beets of any particular age.

It does not seem to be communicated directly from beet to beet.

It has not appeared to any serious extent two years in succession in the same locality.

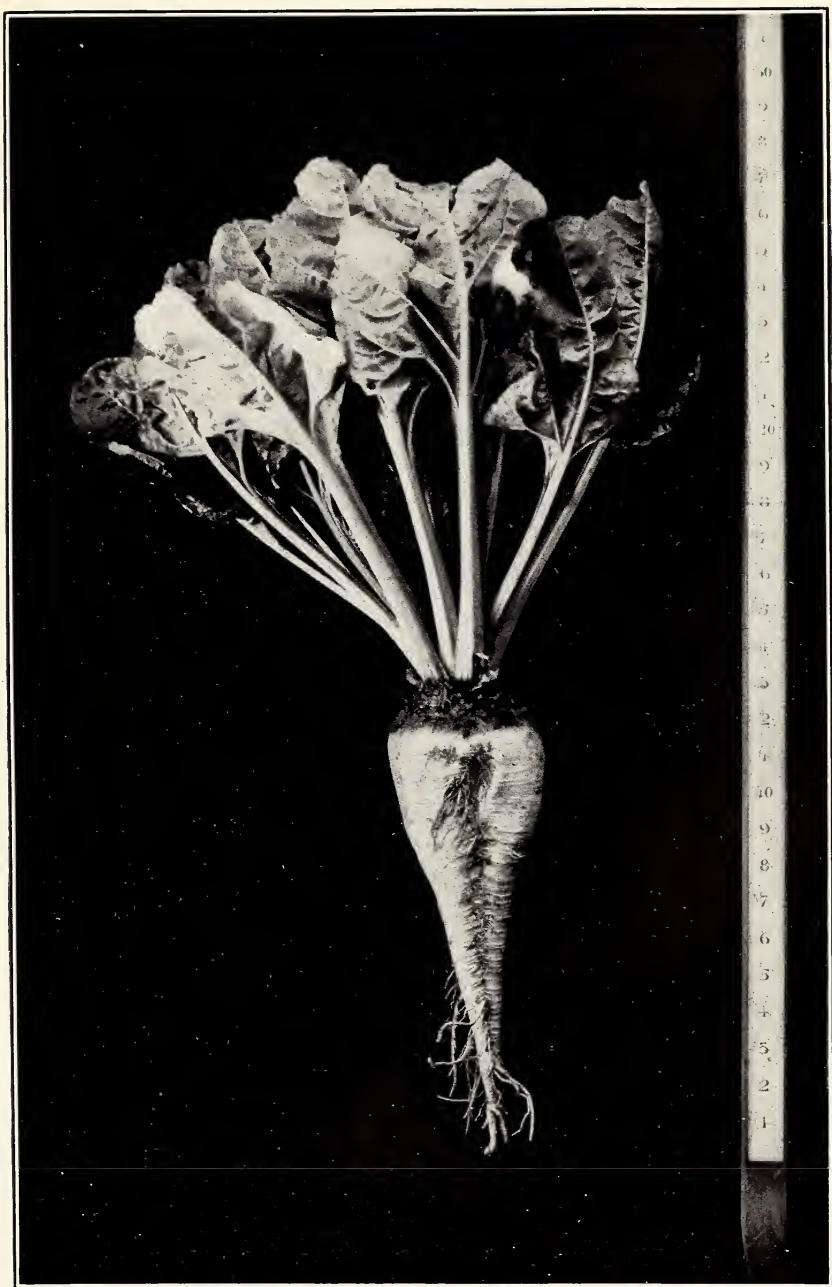
There are indications that a strain of beets resistant to curly-top may be developed.

Growers need not hesitate to plant beets in a field even though their entire crop of beets in that field was destroyed by curly-top the preceding year.

PLATES.

DESCRIPTION OF PLATES.

- PLATE I. (*Frontispiece.*) A sugar beet four months old, showing the usual external symptoms of curly-top—the curled and twisted leaves with greatly shortened stems and poorly-developed blades, but abnormal in number; also the excessive development of side roots on the dwarfed main root. (Natural size.)
- PLATE II. A healthy sugar beet four months old for comparison with the diseased beet shown in Plate I. (About one-fifth natural size.)
- PLATE III. Fig. 1.—Leaves from a sugar beet three months old affected with curly-top; one leaf from each whorl. The rough lower surfaces are apparent as well as the short petioles and undeveloped and twisted blades. (About three-fourths natural size.) Fig. 2.—Leaves from a healthy beet of the same age as that shown in figure 1; one leaf from each whorl. The young leaves are not yet fully expanded. (About one-fourth natural size.)
- PLATE IV. Fig. 1.—Cross section of a healthy leaf through a vein, showing the position of the tissues. Fig. 2.—Section of a leaf through a vein of a curly-top leaf, showing the abnormal position of the fibro-vascular bundle and the unnatural cell development producing among other changes the projections on the lower surface of the leaf.
- PLATE V. Fig. 1.—Cross sections of a sugar beet four months old affected with curly-top. The cuts were made at intervals of 1 inch, beginning 1 inch from the crown. The rings of fibro-vascular bundles show the dark color characteristic of curly-top. The rings are more striking in the larger part of the beet; each section, however, has the dark color. (About natural size.) Fig. 2.—Cross sections of a healthy sugar beet of same size as that shown in figure 1. Fibro-vascular bundles are apparent, but are not dark. The photographs for both figures were taken one hour after cutting. The sections for figure 2 were made at intervals of 1 inch, beginning 1 inch from the crown, as in figure 1. (About natural size.)
- PLATE VI. Fig. 1.—Longitudinal section of a sugar beet four months old affected with curly-top, showing how the dark fibro-vascular bundles are continuous throughout the length of the plant. (About four-fifths natural size.) Fig. 2.—A sugar beet that was obtained in August, 1903, at which time it had all the symptoms of curly-top shown in Plate I. This photograph was made seven months later, and the leaves have almost no curled appearance. The plant appears to have recovered from the curly-top. (About two-sevenths natural size.)
- PLATE VII. Fig. 1.—Beets six weeks old defoliated just above the crown by means of a sharp knife. Conditions for growth remain normal. Fig. 2.—The same plants four weeks later, showing new vigorous tops free from even the slightest symptom of curly-top.
- PLATE VIII. Fig. 1.—Garden beets four months old showing symptoms of curly-top. These beets were in a row on south side of seed beets among which were a number of cases of curly-top. Fig. 2.—Garden beets from same row showing no sign of curly-top.
- PLATE IX. Fig. 1.—Field that was planted to sugar beets and a good stand obtained. Curly-top has destroyed all the beets in the foreground. In the remainder of the field there are many cases of curly-top, but the beets continue to live. Fig. 2.—Field of beets affected with curly-top, showing the possibilities of selection for curly-top resistance. Not more than 1 per cent of these beets are free from curly-top.
- PLATE X. Fig. 1.—Field showing the fourteenth consecutive crop of beets free from curly-top, proving that successive planting of beets without crop rotation will not of itself produce the disease. Figure 2 represents three plants (*A*, *B*, *C*) which received treatment as follows: *A* received an abundant supply of water from below only, *B* received an abundant supply of water from the surface only, and *C* received just enough water to keep the plant alive, but never enough at any one time to soak down to the taproot. The plant *C*, although small, is in all respects perfectly healthy; that is, it possesses no symptoms of curly-top, which shows that an absence of moisture from the taproot is not a condition which in itself will produce curly-top. Plants *A*, *B*, and *C* are of exactly the same age. (About one-eighth natural size.)
- PLATE XI. Fig. 1.—Stem of seed beet affected with curly-top. This plant showed no indication of curly-top during its first season's growth. Fig. 2.—Stem of healthy seed beet for comparison with that shown in figure 1.



A HEALTHY SUGAR BEET FOUR MONTHS OLD.

(About one-fifth natural size.)



FIG. 1.—LEAVES FROM A SUGAR BEET THREE MONTHS OLD AFFECTED WITH CURLY-TOP.
(About three-fourths natural size.)



FIG. 2.—LEAVES FROM A HEALTHY SUGAR BEET THREE MONTHS OLD.
(About one-fourth natural size.)



FIG. 1.—CROSS SECTION THROUGH A VEIN OF A BEET LEAF AFFECTED WITH CURLY-TOP.



FIG. 2.—CROSS SECTION THROUGH A VEIN OF A HEALTHY BEET LEAF.

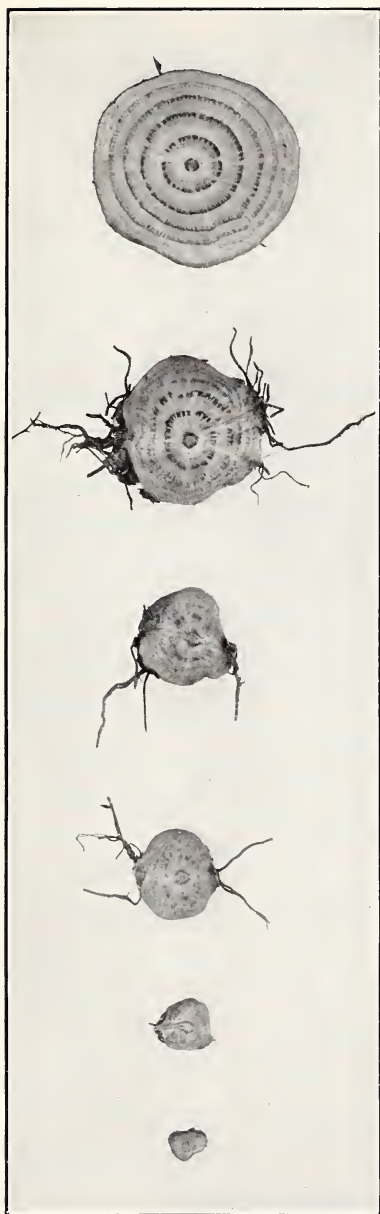


FIG. 1.—CROSS SECTIONS OF A SUGAR BEET FOUR MONTHS OLD AFFECTED WITH CURLY-TOP.

(About natural size.)



FIG. 2.—CROSS SECTIONS OF A HEALTHY SUGAR BEET THREE MONTHS OLD.

(About natural size.)



FIG. 1.—LONGITUDINAL SECTION OF A SUGAR BEET ABOUT FOUR MONTHS OLD AFFECTED WITH CURLY-TOP.

(About four-fifths natural size.)



FIG. 2.—A SUGAR BEET PLANT THAT HAS APPARENTLY RECOVERED FROM AN ATTACK OF CURLY-TOP.

(About two-sevenths natural size.)

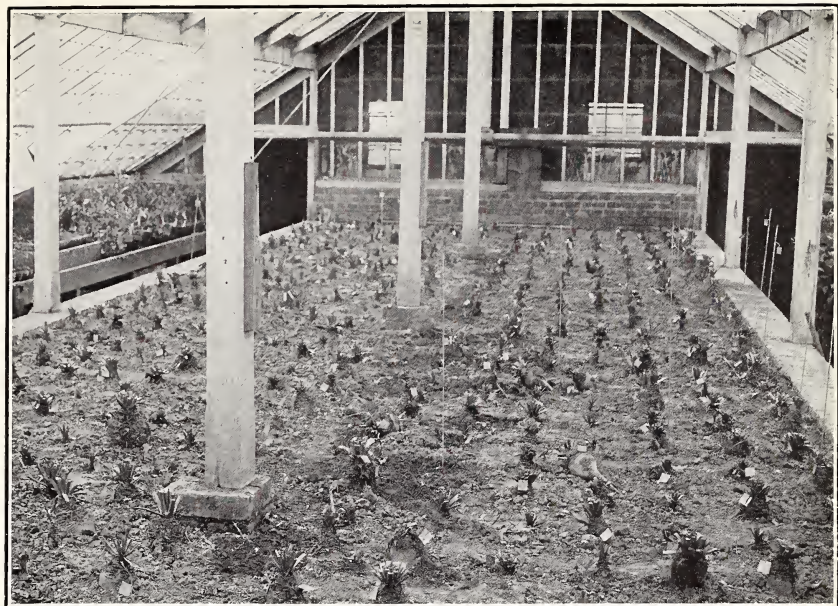


FIG. 1.—BEETS IN GREENHOUSE DEFOLIATED ARTIFICIALLY.



FIG. 2.—THE SAME BEETS SHOWN IN FIGURE 1 WITH NEW TOPS FOUR WEEKS AFTER DEFOLIATION.



FIG. 1.—GARDEN BEETS FOUR MONTHS OLD SHOWING SYMPTOMS OF CURLY-TOP.



FIG. 2.—GARDEN BEETS FOUR MONTHS OLD FREE FROM CURLY-TOP.



FIG. 1.—SUGAR BEET FIELD IN WHICH NEARLY ALL THE PLANTS IN THE FOREGROUND HAVE BEEN DESTROYED BY CURLY-TOP.



FIG. 2.—FIELD OF SUGAR BEETS SERIOUSLY AFFECTED WITH CURLY-TOP, SHOWING HERE AND THERE AN APPARENTLY HEALTHY BEET.



FIG. 1.—THE FOURTEENTH CONSECUTIVE CROP OF SUGAR BEETS IN A FIELD ENTIRELY FREE FROM CURLY-TOP.



FIG. 2.—SUGAR BEET PLANTS THREE MONTHS OLD IN POTS, SHOWING THE EFFECT OF VARIOUS METHODS OF WATERING.
(About one-eighth natural size.)

FIG. 1.—STEM OF SEED BEET AFFECTED WITH CURLY-TOP.



FIG. 2.—STEM OF HEALTHY SEED BEET.



INDEX.

	Page.
Acid, excessive, in soil, probable relation to curly-top.....	24-25
Aeration of soil, relation to curly-top.....	26
Alkali, excessive, in soil, effect on plants.....	23-24
land, occurrence of curly-top.....	9
Amarillo, Tex., experimental farm, note on curly-top.....	27
Arthur, Dr. J. C., study and naming of curly-top.....	10
Atmosphere, abnormal conditions, effect on plants.....	27-28
cold, at time of germination, effect on plants.....	27
Bacteria, disease, name for curly-top.....	10
possible cause of curly-top, experiments.....	14
presence in beets affected with curly-top.....	10-11
Bacteriosis, variant name for curly-top.....	10, 12
Ball, Dr. E. D., opinion on cause of curly-top.....	17
Beet farm, experimental, Utah, occurrence of curly-top.....	9
sugar, belt, occurrence of curly-top.....	9
Beets. <i>See</i> Curly-top, Leaves, Roots, etc.	
Blight, eastern, beet disease.....	8
true, cause.....	13, 14
variant name for curly-top.....	10, 12
western, variant name for curly-top.....	10
Breeding beets resistant to curly-top.....	30-31
“California beet disease,” variant name for curly-top.....	10
Causes, possible, of curly-top.....	13-30
Cercospora beticola, cause of leaf-spot disease.....	8
true blight.....	13, 14
Chlorid, mercuric, use in combating curly-top.....	16
Cold, relation to curly-top.....	20
Contagion, curly-top, study.....	31
Copper sulphate solution, use on diseased plants.....	16-17
Crown, cavity, possible symptom of curly-top.....	8
Cultivation of plants, improper, relation to curly-top.....	25-26
Curly-top, choice of name, reasons.....	13
communicability, experiments.....	31
development of resistant strain of beets.....	30-31
history.....	8-10
investigations, experiments at Department greenhouses.....	15-16
in Indiana.....	10-11
results, summary.....	32
names of the disease.....	10-13
nonconsecutive appearance.....	30
occurrence.....	8-10
outbreak, 1900.....	9

	page.
Curly-top, percentage of young plants attacked.....	10
persistence.....	31-32
possible causes.....	13-30
symptoms.....	7-8
unequal distribution over infested area.....	9-10
Damping-off, relation to curly-top.....	19
Defoliation of plants, experiments in curly-top investigations.....	15
Disease resistance of beets, development by breeding.....	30-31
Drought, relation to curly-top symptoms.....	18
Fertility of soil, relation to curly-top.....	22
Fungi, possible cause of curly-top, experiments.....	14-17
Fungicides, experiments with diseased plants.....	16-17
Fungus from diseased fields, inoculation, experiments.....	15-16
Garland, Utah, experimental field, note on curly-top.....	9
Germination, relation to curly-top.....	27
Golden, Katherine E., investigations of curly-top in Indiana.....	10-11
Greenhouse experiments, conclusion as to cause of curly-top.....	19
normal conditions, effect on diseased plants.....	17
Gummosis, bacterial, variant name for curly-top.....	12
Hairy-root, variant name for curly-top.....	10, 13
Hedgcock, Dr. George G., early observation of curly-top.....	8
Humus, insufficient, in soil, effect on plants.....	22-23
Huston, Professor, discovery of curly-top in Indiana.....	10
Indiana, investigations of curly-top.....	10-11
Irrigated lands, occurrence of curly-top.....	9
Insects, relation to curly-top.....	17
Lapham and Heileman, observations of soil in relation to curly-top.....	24
Leaf conditions not responsible for curly-top.....	14-15
development in plants affected with curly-top.....	17
hopper, beet.....	17
spot, beet disease.....	8
Leaves, attacks by fungi possible cause of curly-top.....	14-15
diseased plants, appearance.....	7
Lime, deficiency as cause of curly-top.....	24
Mercuric chlorid solution, use on diseased plants.....	16-17
Moisture supply, abnormal, effect on plants.....	18-20
variable, effect on plants.....	19-20
Names of curly-top.....	10-13
Nomenclature of curly-top.....	10-13
Parasites, experiments to determine relation to curly-top.....	29
Persistence of curly-top.....	31-32
Plant food, insufficient, in soil, relation to curly-top.....	21-22
Plates, description.....	34
Rainfall after drought, relation to disease, opinion of Doctor Wilhelmj.....	29-30
Resistance of beets to curly-top, development by breeding.....	30-31
Roots, diseased plants, appearance.....	7
fungous attacks as cause of curly-top.....	15
insufficient supply of air, relation to curly-top.....	26
Seed bed, cold, effect on plants.....	20-21
dry, effect on plants.....	18
preparation, improper, relation to curly-top.....	25
warm, effect on plants.....	21
wet, effect on plants.....	19
poor, relation to curly-top.....	28-29

	Page
Soil, acidity, effect on plants	24-25
alkalinity, effect on plants	23-24
conditions, abnormal, effect on plants	20-26
diseased field, experiments with healthy plants	15-16
insufficient humus, effect on plants	22-23
plant food, effect on plants	21-22
“Stunted beets,” variant name of curly-top	10, 13
Subsoil, hard, effect on plants	21
Sulphate, copper, use in combating curly-top	16
Summary of bulletin	32
Symptoms of curly-top and other diseases	7-8, 11
Taproot, insufficient moisture, effect on plants	18-19
Temperature, air, relation to cause of curly-top	27
* soil, relation to curly-top	20-21
Varieties of beets attacked by curly-top	9
Water, cold, effect on plants	20
logging, relation to curly-top	19
“Whiskered beets,” variant name for curly-top	10, 13
White fly, cause of curly-top, opinion of Doctor Ball	17
Wilhelmj, Dr. A., opinion as to cause of curly-top	19, 29-30
Wilting of leaves, symptom of curly-top	8
Windbreaks, use as protection from curly-top	27
Winds, hot, dry, effect on plants	27-28
Young plants, susceptibility to curly-top	9

